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(54) **CRACK RESISTANT COMBUSTOR**

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F23R 3/34 (2006.01)

(52) **U.S. Cl.**

CPC ***F23R 3/283*** (2013.01); ***F23R 3/343*** (2013.01); *F23R 2900/00005* (2013.01); *Y10T 29/4932* (2015.01); *Y10T 29/49346* (2015.01)

(58) **Field of Classification Search**

CPC F23R 3/283; F23R 3/343; F23R 2900/00005; Y10T 29/49346; Y10T 29/4932
USPC 60/752, 754, 755, 757
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,016,703	A	1/1962	Andre et al.	
4,242,871	A *	1/1981	Breton	60/757
4,413,477	A *	11/1983	Dean et al.	60/757
4,614,082	A	9/1986	Sterman et al.	
6,101,814	A	8/2000	Hoke et al.	
6,792,757	B2 *	9/2004	Borns et al.	60/772
6,986,201	B2 *	1/2006	Moertle et al.	29/890.01
2003/0115886	A1	6/2003	Farmer et al.	
2009/0077975	A1 *	3/2009	Scholz et al.	60/752

FOREIGN PATENT DOCUMENTS

EP	1160512 A2	12/2001
GB	1531690 A	11/1978

OTHER PUBLICATIONS

Search Report and Written Opinion for PCT/US2006/009218.

* cited by examiner

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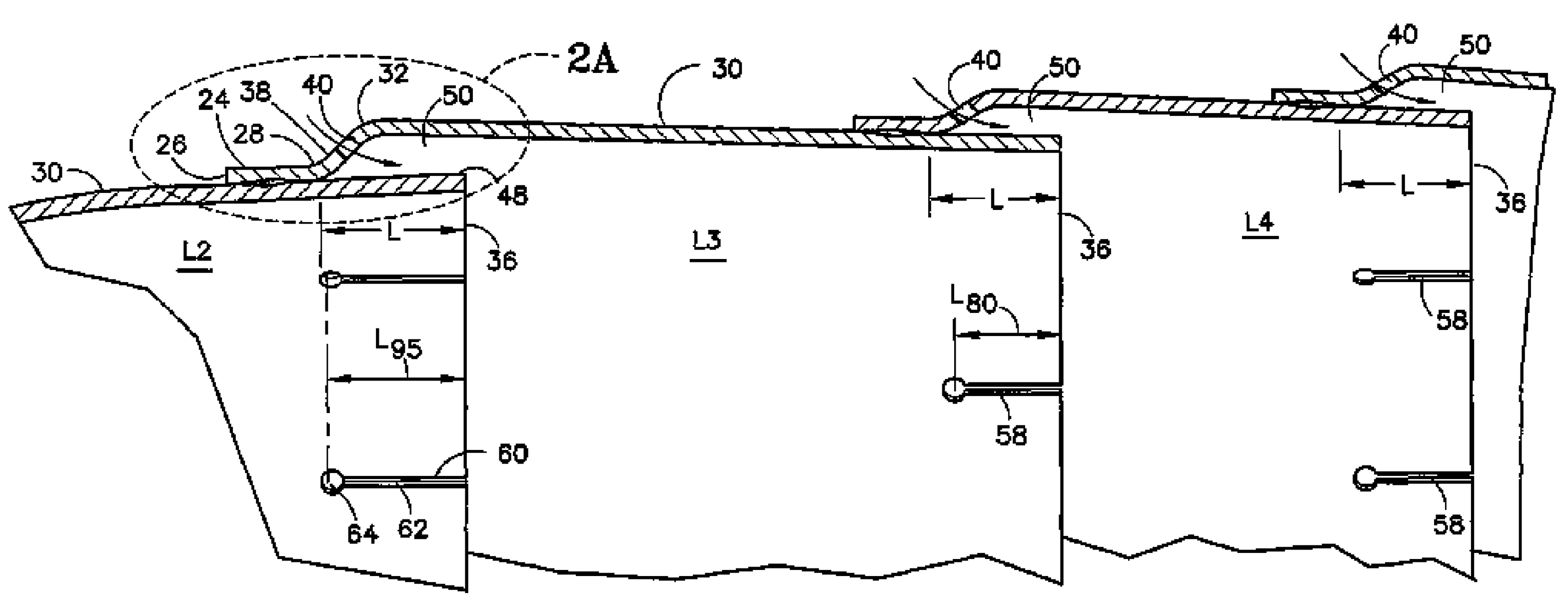
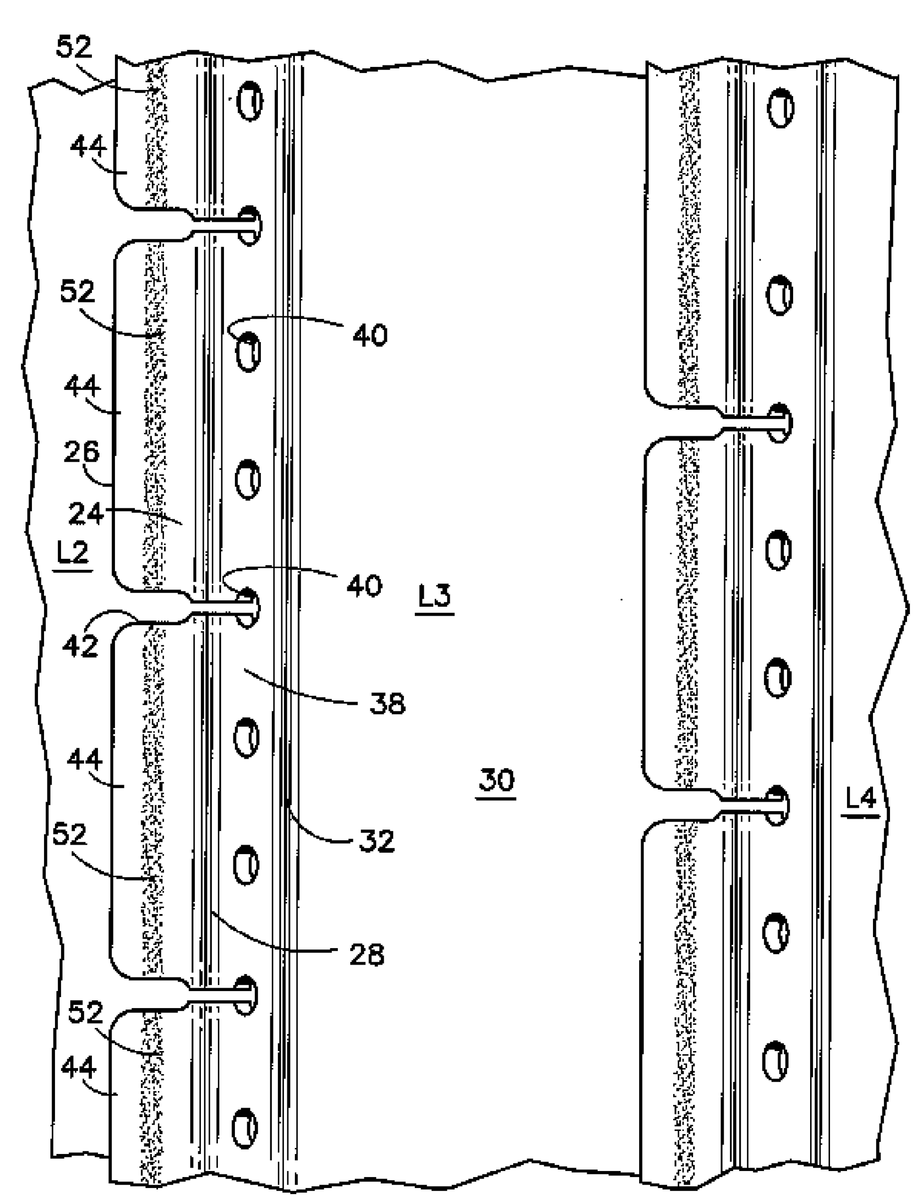
(57) **ABSTRACT**

A combustion chamber louver assembly includes an aft louver having a forward panel **24** that extends axially from a louver leading edge **26** to a corner **28**, and a forward louver joined to the forward panel of the aft louver. A lip **48** defined by a portion of the forward louver that extends axially past the corner to a louver trailing edge **36** includes circumferentially distributed trailing edge slots **60** extending forwardly from the trailing edge a nominal distance equal to about 88% to 95% of the length L of the lip.

18 Claims, 4 Drawing Sheets





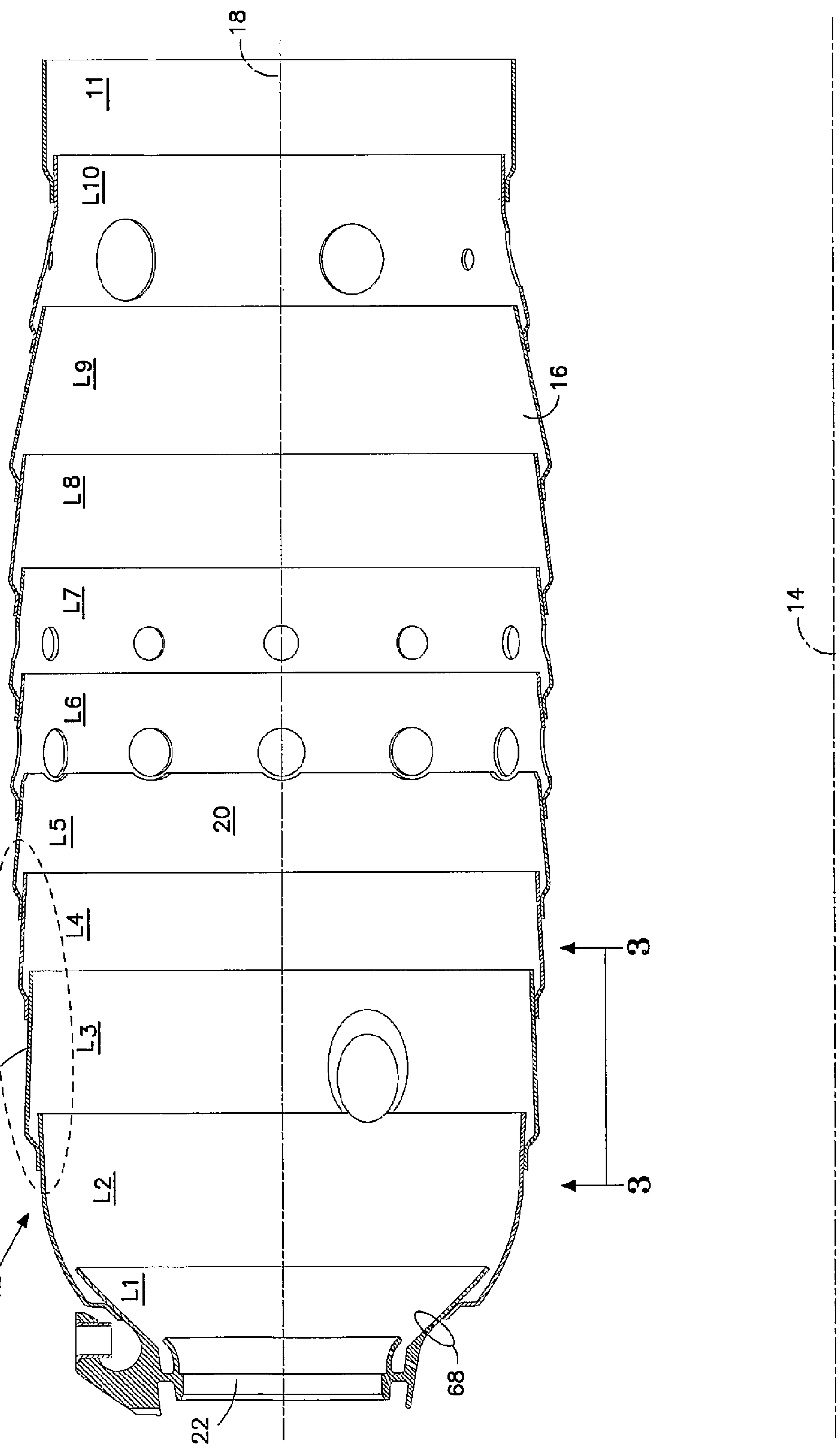
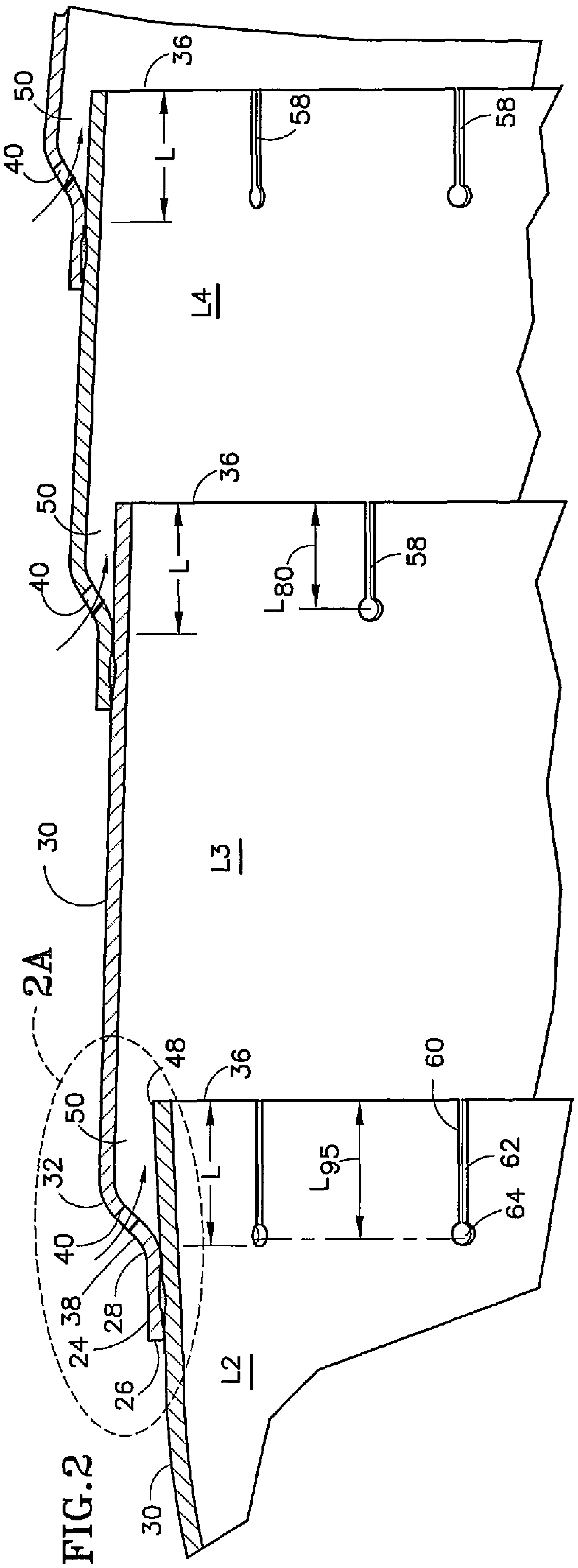


FIG.1


50
40
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L
L4
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L
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L3
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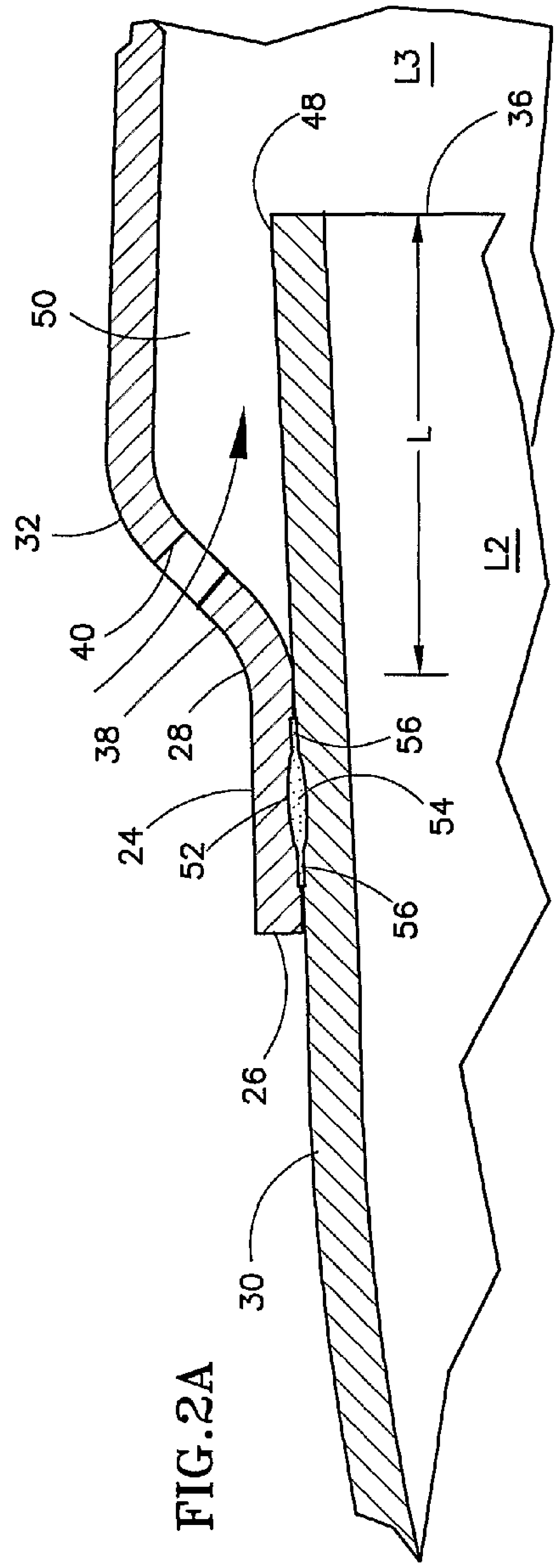
50
32
40
38
28
24
26
L
L95
60
62
64
L2
30

FIG. 2


L3
48
36
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32
40
38
28
L
L2
56
24
52
54
56
26
30

FIG. 2A

FIG. 3

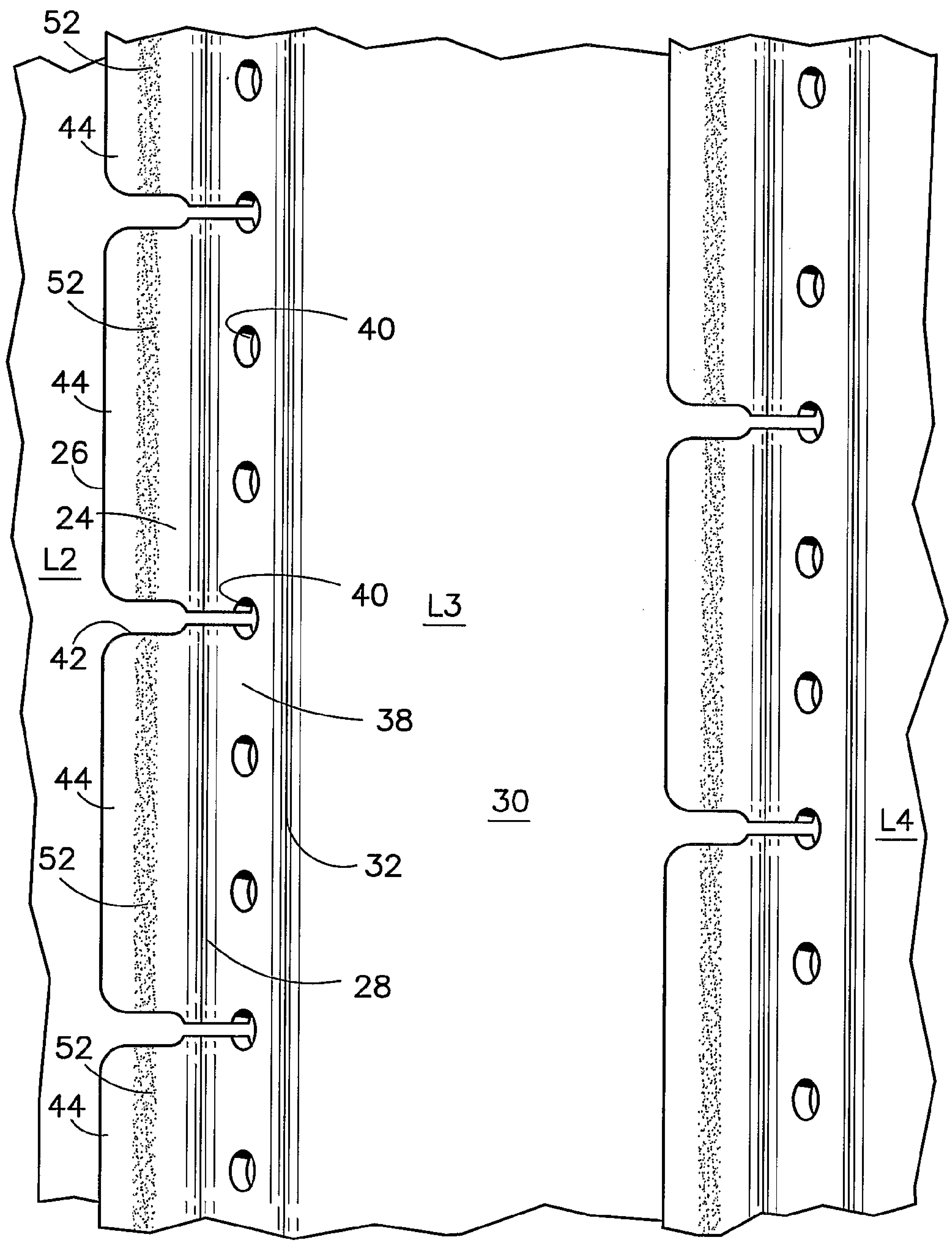


FIG.4

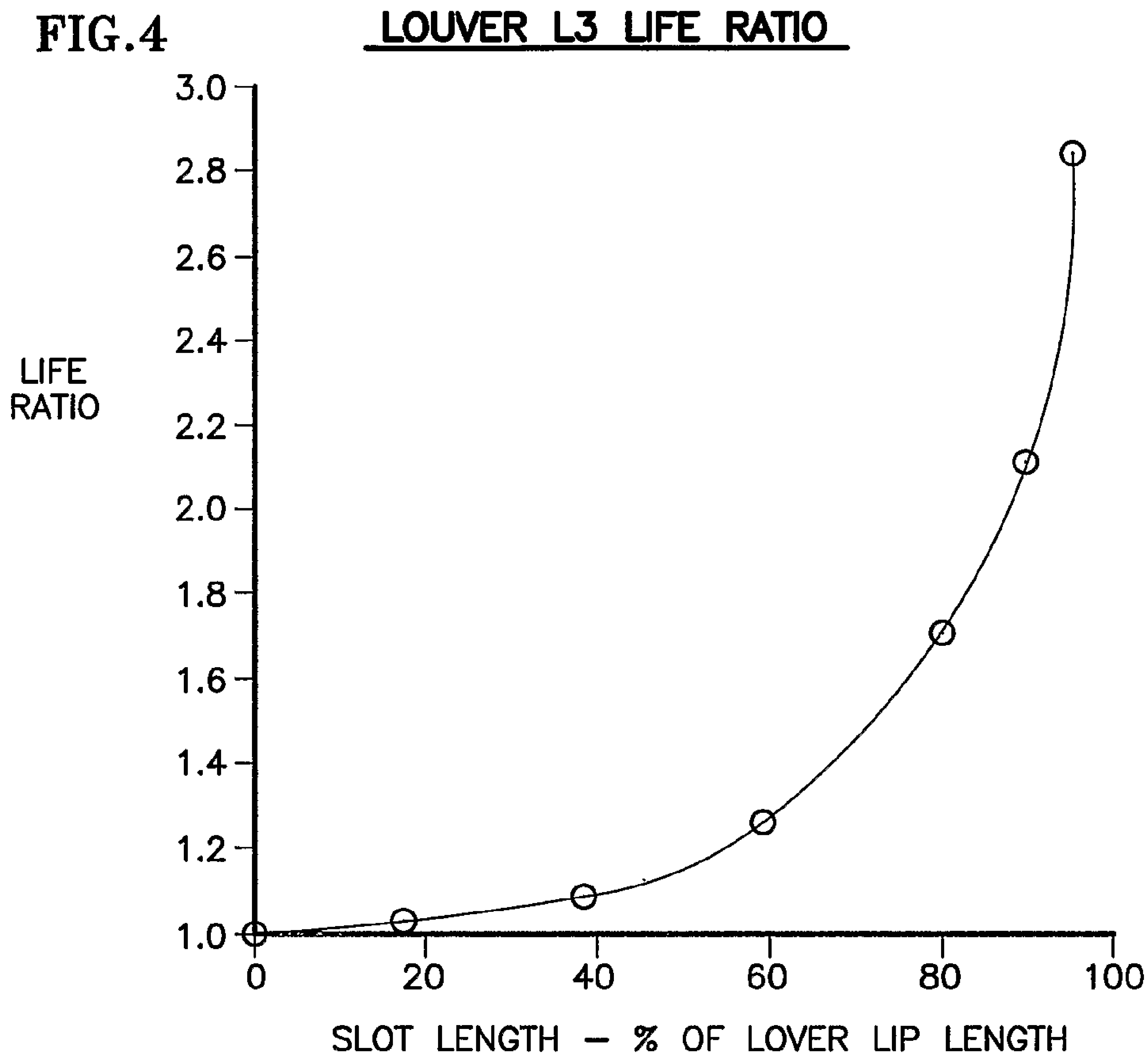
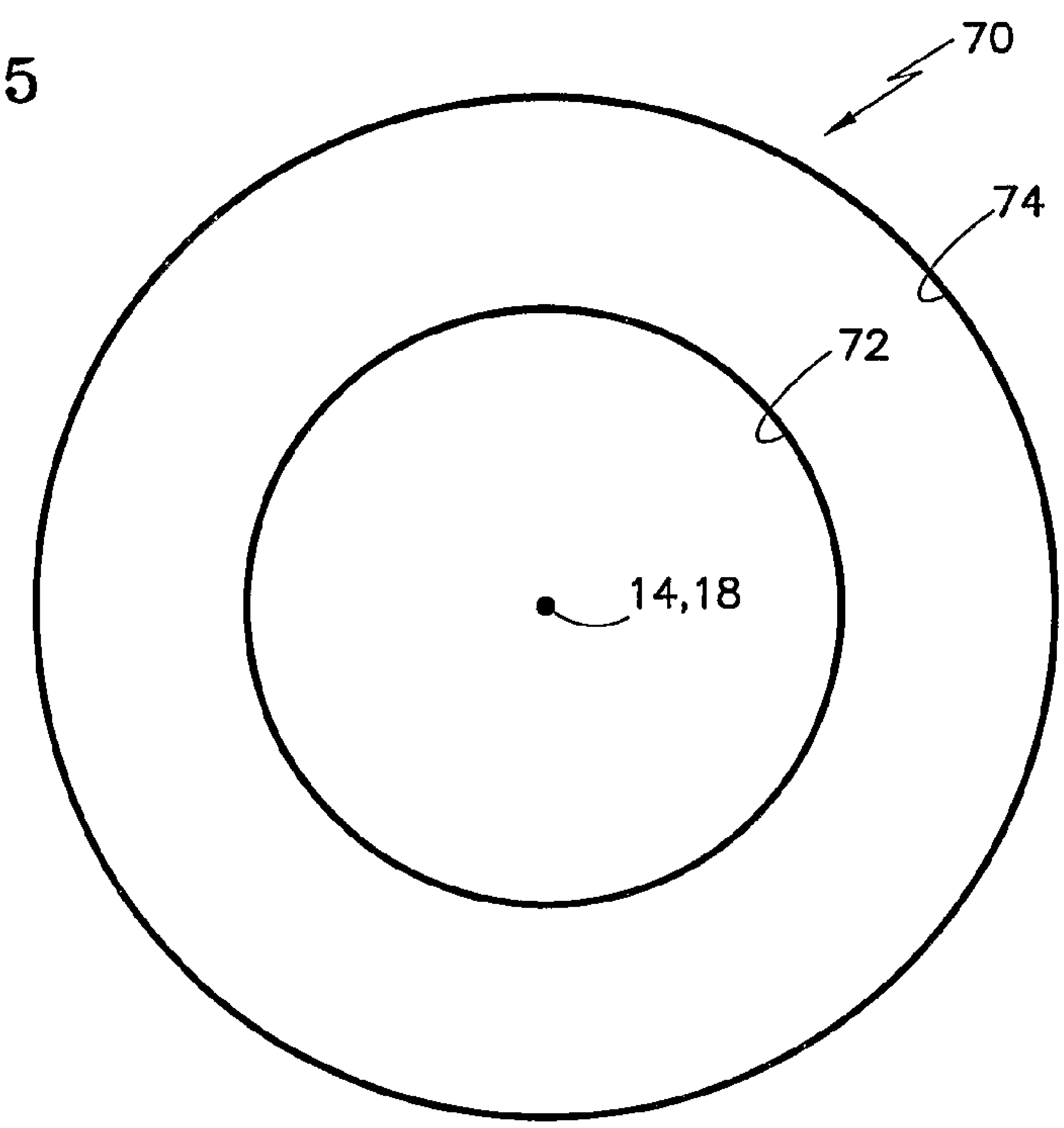

LOUVER L3 LIFE RATIO
LIFE RATIO
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0
20
40
60
80
100
SLOT LENGTH — % OF LOVER LIP LENGTH

FIG.5


70
74
72
14,18

CRACK RESISTANT COMBUSTOR

TECHNICAL FIELD

This invention relates to combustion chamber liners for turbine engines and specifically to a crack resistant combustion chamber louver assembly.

BACKGROUND

Turbine engine combustion chamber liners may be made of multiple, axially successive louvers circumscribing a combustion chamber centerline. A typical louver has a forward panel, an aft panel and a short bulkhead that projects radially to connect the forward and aft panels to each other. A louver assembly comprises a forward louver and an aft louver arranged so that the aft panel of the forward louver nests radially inside the forward panel of the aft louver. The aft panel of the forward louver also extends axially past the connecting bulkhead of the aft louver to define a lip. A weld joint extends circumferentially to join the forward panel of the aft louver to the aft panel of the forward louver. The lips of certain louvers, particularly louvers that are not near the axially forward end of the liner, may include a series of circumferentially distributed slots. These lip slots help relieve thermal stresses that could cause cracks in the lips of those louvers. Experience shows that such lip slots are unnecessary in the louvers residing closer to the forward end of the liner.

Turbine engine manufacturers strive to minimize undesirable exhaust emissions arising from combustion of a fuel and air mixture in the combustion chamber. U.S. Pat. Nos. 6,101,814 and 6,715,292 (the contents of both of which are incorporated herein by reference) describe a combustor liner and associated fuel injector that produce considerably reduced emissions in comparison to early generation combustion liners. Throughout this specification the low emissions liner described in the aforementioned patents will be referred to as an intermediate generation liner; the predecessor to the intermediate generation liner will be referred to as an early generation liner. Experience reveals that a louver near the forward end of the early generation liner, specifically the second louver L**2**, does not require lip slots in order to resist cracking of the lip. Similarly, no lip slots are required in the second louver L**2** of the intermediate generation liner to resist cracking of the lip. However in the intermediate generation liner, the forward panel of the axially adjacent aft louver (louver L**3**) exhibits susceptibility to cracking in the immediate vicinity of the weld joint that secures the louvers to each other. The cracking is believed to arise because a portion of forward louver L**2** that is relatively hot during engine operation nests radially inside of a portion of aft louver L**3** that is relatively cool during engine operation. The relatively cool portion of aft louver L**3** is unable to withstand the cyclic, thermally induced radial expansion (and contraction) of the relatively hot portion of forward louver L**2**. The cracking is undesirable because it requires more frequent inspections than would otherwise be necessary and may also require replacement or reconditioning of an otherwise serviceable liner or its louvers.

What is needed is a combustor liner louver assembly whose louvers exhibit improved forward panel crack resistance.

SUMMARY

One embodiment of the louver assembly described herein includes an aft louver having a forward panel that extends axially from a louver leading edge to a corner, and a forward louver joined to the forward panel of the aft louver. A lip defined by a portion of the forward louver that extends axially past the corner to a louver trailing edge includes circumferentially distributed trailing edge slots extending forwardly from the trailing edge a nominal distance equal to about 88% to 95% of the length of the lip.

The foregoing and other features of the various embodiments of the louver assembly will become more apparent from the following description of the preferred embodiment and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a side elevation view of a combustor can comprising multiple, axially successive louvers L**1** through L**11**.

FIG. **2** is a perspective view of a portion of the combustor can of FIG. **1**.

FIG. **2**A is an enlarged, view of portion **2**A of FIG. **2**.

FIG. **3** is a developed view taken in the direction **3-3** of FIG. **1**.

FIG. **4** is a graph showing the improved service life of a louver assembly as disclosed herein.

FIG. **5** is a schematic illustration of an annular combustor

DETAILED DESCRIPTION

This invention is predicated in part on the recognition that crack susceptibility in the forward panel of a louver is related to differences in thermal expansion of that louver relative to an adjacent louver. Moreover, the remedy for mitigating the crack susceptibility involves modifying the adjacent louver at a location offset from the crack initiation site of the crack susceptible louver.

FIGS. **1**, **2** and **2**A show a combustion chamber liner **12'** for a gas turbine engine. The illustrated liner is a combustor can and is one of nine such cans circumferentially distributed about an engine axis **14** to form a can-annular combustor. Each liner **12** includes eleven axially successive louvers **16** (individually labeled L**1** through L**11**) each in the form of an integral ring. Each liner circumscribes a combustion chamber centerline **18** to define a combustion chamber **20**. A fuel injector, not shown, projects through opening **22** at the forward end of the can. A typical louver **16** has a forward panel **24** extending axially from a louver leading edge **26** to a rounded, radially inner corner **28**, and an aft panel **30** extending from a rounded, radially outer corner **32** to a louver trailing edge **36**. A bulkhead **38** projects radially outwardly from the forward louver to connect the forward and aft panels to each other. Circumferentially distributed coolant admission holes **40** penetrate the bulkhead. The holes in louver L**2** are all of equal size. The holes **40** in louvers L**3** through L**11** are grouped in clusters of holes. Each cluster occupies a sector of the bulkhead circumference. All the holes in a given cluster are of the same size (i.e. flow area) however the holes in a given cluster are not necessarily the same size as the holes in other clusters. The described clustering arrangement accommodates the three dimensional distribution of gas temperature in the combustion chamber.

Referring additionally to FIG. **3**, twenty four circumferentially distributed flexure slots, such as slot **42**, define a series of tabs **44** in the forward panel of louvers L**3** through L**11**. Each slot extends from the louver leading edge **26** to an associated coolant hole **40**, however only one of every three coolant holes is associated with a flexure slot. The flexure slots impart flexibility to the forward panels to facilitate mating of axially adjacent louvers.

As seen best in FIGS. **2** and **2**A, a louver assembly comprises a forward, radially inner louver such as L**2**, and an aft, radially outer louver such as L**3** arranged so that part of the aft panel **30** of the forward louver nests radially inside the forward panel **24** of the aft louver. The aft panel of the forward louver also extends axially past the bulkhead **38** of the aft louver to define a lip **48**. Specifically, the aft panel of the forward louver extends axially past the radially inner corner **28** of the aft louver to define the lip **48** and an associated annulus **50**. The lip has a length L measured from the trailing edge to the radially inner corner **28**. The annulus receives a coolant fluid by way of the coolant holes **40**. The coolant forms a coolant film on the louvers to help protect them from the intense heat of combustion occurring inside the combustion chamber **20**.

A weld joint **52** joins the forward louver to the forward panel of the aft louver. As seen best in FIG. **3**, the weld joint is circumferentially quasi-continuous since it is locally interrupted by the flexure slots **42**. The weld joint includes a weld nugget **54** axially bordered by regions of weld runout **56** (FIG. **2**A).

Referring to FIG. **2**, louvers L**3** through L**10** include twenty four circumferentially distributed lip slots **58**. Each lip slot has a keyhole configuration comprising a linear portion and a circular or otherwise rounded terminus. Each lip slot **58** is circumferentially aligned with one of the twenty four flexure slots **42** in the same louver. However the lip slots of a given louver are circumferentially offset from the flexure slots of the axially neighboring louver by 7.5 degrees. Each lip slot, as measured from the louver trailing edge to the center of the circular terminus, has a length L_{80} of about 80% of the length L of the louver lip. Since the lips on louvers L**3** through L**10** are all about 0.350 inches (0.89 centimeters) long, each of the slots is about 0.280 inches (0.71 centimeters) long. These slots **58** help relieve thermal stresses that could cause cracks in the lips of the louvers L**3** through L**10**.

In early generation liners, the dilution hole pattern differs from that of the intermediate generation liners, and the lip of louver L**2** is devoid of slots analogous to slots **58**. Experience has shown that the lip of louver L**2** in these early generation liners is not susceptible to cracking related to thermal stress. The intermediate generation liners employ the dilution hole pattern described in the patents incorporated herein by reference, but, like the early generation liners, also do not employ slots analogous to slots **58** in louver L**2**. These intermediate generation liners also are not known to be susceptible to cracking in the lip of louver L**2**. However the intermediate generation liners exhibit a susceptibility to cracking in the relatively cool forward panel **24** of aft louver L**3**. The crack initiation site is aft of the weld runout **56** immediately aft of the weld nugget **54**. This cracking of the forward panel of aft louver L**3** is believed to arise from thermally induced radial expansion of the relatively hot portion of louver L**2** (which is the forward louver from the perspective of louver L**3**) in the vicinity of the forward panel **24** of louver L**3**. The cracking of the forward panel is believed to occur in the intermediate generation liner, but not in the early generation liner, because of a modified gas temperature distribution arising from interactions attributable to the dilution hole pattern and the innovative fuel injector described in the patents incorporated by reference.

Louver L**2** includes circumferentially distributed trailing edge slots **60** axially offset from the forward panel of louver L**3**. The slots are keyhole slots comprising a linear portion **62** and a circular or otherwise rounded terminus **64**. Each trailing edge slot **60** is circumferentially aligned with one of the twenty four flexure slots **42** in louver L**2**. However the trailing edge slots of louver L**2** are circumferentially offset from the flexure slots of louver L**3** by 7.5 degrees. The slots **60** extend forwardly from the trailing edge **36** of louver L**2** a nominal distance L_{95} equal to about 88% to 95% of the length L of the lip and preferably about 95% of the length L of the lip. The nominal distance is the distance from the trailing edge **36** to the center of the circular terminus **64**. The length L of the lip on louver L**2** is about 0.425 inches (1.08 centimeters). Accordingly, the preferred length of the slot is about 0.405 inches (1.03 centimeters).

FIG. **4** shows a graph of the predicted life of louver L**3** expressed as the life of a slotted louver divided by the life of an unslotted louver (i.e. a louver with a trailing edge slot length of zero) where louver life is measured in engine cycles. The life expectancy is shown as a function of slot length expressed as a percentage of lip length. The prediction is based on a coarse grid finite element model of a sector of the disclosed liner. As is evident from the graph, the slot in louver L**3** yields an impressive gain in louver life.

Intermediate generation combustion liners can be upgraded by cutting through louver L**1** at the approximate location **68** (FIG. **1**) thereby allowing the aft end of louver L**1** and louvers L**2** through L**11** to be separated as a unit from the forward end of L**1**. The separated louver assembly can then be scrapped or recycled. An upgraded louver assembly comprising the aft end of a louver L**1** and louvers L**2** through L**11** and also including the trailing edge slots **60** in L**2** is then attached, for example by welding, to the residual forward end of the original louver L**1**. As already described, the trailing edge slots **60** measure about 88% to 95% and preferably 95% of the length L of the louver lip. This upgrade method is not only time efficient but is also cost effective because the forward end of L**1** is the most costly part of the liner.

Combustor liners can also be upgraded, albeit less cost effectively and less time efficiently, by installing the trailing edge slots **60** in an unslotted louver (e.g. louver L**2**) of those liners. The upgrade involves removing the unslotted louver from the liner, and securing a slotted louver having trailing edge slots measuring about 88% to 95% and preferably 95% of the length L of the louver lip to the liner in place of the unslotted louver. The slotted louver may be the same louver as the previously unslotted louver upgraded to include the slots **60**, or may be a newly manufactured replacement louver or may be a used, previously unslotted louver taken from a pool of louvers that have been upgraded by installing the slots **60** therein.

The foregoing discussion describes the liner and associated method of upgrade in the context of a combustor can for a can-annular combustor. However as seen in FIG. **5**, the concept can be applied to the louvers of an annular combustor **70** having radially inner and outer liners **72**, **74** constructed of louvers substantially as already described.

Although this disclosure refers to specific embodiments, it will be understood by those skilled in the art that various changes in form and detail may be made without departing from the subject matter set forth in the accompanying claims.

We claim:

1. A combustion chamber louver assembly, comprising:

an aft louver having a forward panel that extends axially aft from a louver leading edge to a corner of the forward panel of the aft louver; and a forward louver joined to the forward panel of the aft louver and having a lip defined by a portion of the forward louver that extends axially aft past the corner of the forward panel of the aft louver to a louver trailing edge, the lip having a length L and including circumferentially distributed trailing edge slots extending forwardly from the trailing edge a nominal distance equal to about 88% to 95% of the length of the lip.

2. The louver assembly of claim **1** wherein the nominal distance is equal to about 95% of the length L of the lip.

3. The louver assembly of claim **1** wherein the aft louver is a radially outer louver and the forward louver is a radially inner louver.

4. The louver assembly of claim **1** wherein the slots are keyhole slots.

5. The louver assembly of claim **1** including a bulkhead projecting from the corner and wherein fluid admission holes penetrate the bulkhead.

6. The louver assembly of claim **5** wherein the fluid admission holes are not all equal in size.

7. The louver assembly of claim **1** in which circumferentially distributed flexure slots define a series of tabs in the forward panel.

8. The louver assembly of claim **7** in which the flexure slots are circumferentially aligned with the trailing edge slots.

9. The louver assembly of claim **1** including a bulkhead projecting from the corner and fluid admission holes penetrating the bulkhead and wherein circumferentially distributed flexure slots define a series of tabs in the forward panel, the flexure slots extending from the leading edge to an associated fluid admission hole.

10. The louver assembly of claim **1** wherein the forward louver is joined to the forward panel of the aft louver by a weld joint.

11. A turbine engine combustor can including the louver assembly of claim **1**.

12. An annular turbine engine combustor liner including the louver assembly of claim **1**.

13. The combustion chamber louver assembly of claim **1** wherein the forward louver is a radially inner louver including circumferentially distributed flexure slots defining a series of tabs, the aft louver is a radially outer louver and wherein the trailing edge slots reduce reducing radial thermal growth related crack susceptibility in the forward panel of the aft louver.

14. A method of upgrading a combustion chamber liner having multiple, axially adjacent louvers, comprising the steps of:

cutting through a selected louver to separate an aft end of the selected louver and louvers aft of the selected louver from a residual forward end of the selected louver, the selected louver being a louver forward of a louver that requires an upgrade; and

securing an upgraded louver assembly to the residual forward end of the selected louver, wherein one of the separated louvers aft of the selected louver has a lip devoid of trailing edge slots and wherein the upgraded louver assembly includes an upgraded counterpart of the one louver, the upgraded counterpart including a lip with a lip length L and also including trailing edge slots measuring about 88% to 95% of the lip length L.

15. The method of claim **14** wherein the trailing edge slots measure about 95% of the lip length L.

16. The method of claim **14** wherein the liner has eleven louvers and the selected louver is the forwardmost of the eleven louvers.

17. A method of upgrading a combustion chamber liner having multiple, axially adjacent louvers, comprising the steps of:

removing an unslotted louver from the liner; and

securing a slotted louver having trailing edge slots measuring about 88% to 95% of a length L of a louver lip to the combustion chamber liner in place of the unslotted louver.

18. The method of claim **17** wherein the trailing edge slots measure about 95% of the length L of the louver lip.

* * * * *